8.3.6 Longitudinal torsional reinforcement Longitudinal torsional reinforcement shall be provided to resist the following design tensile forces, taken as additional to any design tensile forces due to flexure:

(a) In the flexural tensile zone, a force of—

$0.5 f_{sy.f} (A_{sw}/s) u_t \cot^2\theta_t$; and

(b) In the flexural compressive zone, a force of—

$0.5 f_{sy.f} (A_{ws/s}) u_t \cot^2\theta_t - F^*_c$; but not less than zero,

where

u_t = the perimeter of the polygon defined for A_t.

F^*_c = the absolute value of the design force in the compression zone due to flexure.

8.3.7 Minimum torsional reinforcement Where torsional reinforcement is required by Clause 8.3.4—

(a) all of the minimum shear reinforcement required by Clause 8.2.8 shall be provided in the form of closed ties; and

(b) longitudinal torsional reinforcement shall be provided in accordance with Clause 8.3.6.

8.3.8 Detailing of torsional reinforcement Torsional reinforcement shall be detailed in accordance with the following:

(a) Torsional reinforcement shall consist of both closed ties and longitudinal reinforcement.

(b) The closed ties shall be continuous around all sides of the cross-section and anchored so as to develop full strength at any point, unless a more refined analysis shows that over part of the tie full anchorage is not required. The spacing, s, of the closed ties shall not exceed the lesser of $0.12u_t$ and 300 mm.

(c) The longitudinal reinforcement shall be placed as close as practicable to the corners of the cross-section, and in all cases at least one longitudinal bar shall be provided at each corner of the closed ties.

8.4 LONGITUDINAL SHEAR IN BEAMS

8.4.1 Application This Clause applies to the transfer of longitudinal shear forces, across interface shear planes through webs and flanges of composite beams, and across shear planes through flanges cast monolithically.

8.4.2 Design shear force For the purpose of this Clause, the design longitudinal shear force acting on a shear plane shall be taken as—

(a) For a shear plane through a flange, equal to V^*A_1/A_2

where

(i) for a flange in compression—

A_1/A_2 = the ratio of the area of flange outstanding beyond the shear plane to the total area of flange;

(ii) for a flange in tension—

A_1/A_2 = the ratio of the area of longitudinal reinforcement in the flange outstanding beyond the shear plane to the total area of longitudinal tensile reinforcement.

(b) For a shear plane through the web, equal to V^*.

8.4.3 Design shear strength The design longitudinal shear strength shall be taken as ϕV_{uf} where -

$$V_{uf} = \beta_4 A_s f_{sy} d/s + \beta_5 b_f d f'_{ct} \leq 0.2 f'_c b_f d$$

where

β_4, β_5 = the shear plane surface coefficients given in Clause 8.4.4

A_s = cross-sectional area of reinforcement anchored each side of the shear plane

f_{sy} = the yield strength of the reinforcement crossing the shear plane

d = effective depth of the composite beam

s = spacing of reinforcement crossing the shear plane

b_f = the width of the shear interface

f'_{ct} = the characteristic principal tensile strength of the concrete.

8.4.4 Shear plane surface coefficients The shear plane surface coefficients, β_4 and β_5, for the surface condition of the shear plane, shall be determined from Table 8.4.4, except that where the beam is subject to high levels of differential shrinkage, temperature effects, tensile stress, or fatigue effects across the shear plane, the value of β_5 should be reduced.

TABLE 8.4.4

SHEAR PLANE SURFACE COEFFICIENTS

Surface condition of the shear plane	Coefficients	
	β_4	β_5
A smooth surface, as obtained by casting against a form, or finished to a similar standard	0.6	0.1
A surface trowelled or tamped, so that the fines have been brought to the top, but where some small ridges, indentations or undulations have been left; slip-formed and vibro-beam screeded; or produced by some form of extrusion technique.	0.6	0.2
A surface deliberately roughened— (a) by texturing the concrete to give a pronounced profile; (b) by compacting but leaving a rough surface with coarse aggregate protruding but firmly fixed in the matrix; (c) by spraying when wet, to expose the coarse aggregate without disturbing it; or (d) by providing mechanical shear keys.	0.9	0.4
Monolithic construction	0.9	0.5

8.4.5 Shear plane reinforcement Where reinforcement is required to increase the longitudinal shear strength, the reinforcement shall consist of shear reinforcement anchored to develop its full strength at the shear plane. Shear and torsional reinforcement already provided and which crosses the shear plane, may be taken into account for this purpose.

An area of shear reinforcement not less than $0.35 b_f s / f_{sy.f}$ shall be provided.

8.4.6 Minimum thickness of structural components The average thickness of structural components subject to interface shear shall be not less than 50 mm with a minimum local thickness not less than 30 mm.

8.5 DEFLECTION OF BEAMS

8.5.1 General The deflection of a beam shall be determined in accordance with Clause 8.5.2 or Clause 8.5.3.

Alternatively, for reinforced beams, the span-to-effective depth ratio shall comply with Clause 8.5.4.

8.5.2 Beam deflection by refined calculation The calculation of the deflection of a beam by refined calculation shall make allowance for the following:

(a) Shrinkage and creep properties of the concrete.

(b) Expected load history.

(c) Cracking and tension stiffening.

8.5.3 Beam deflection by simplified calculation

8.5.3.1 *Immediate deflection* The immediate deflections due to external loads and prestressing, which occur immediately on their application, shall be calculated using the value of E_{cj} determined in accordance with Clause 6.1.2 and the value of the effective second moment of area of the member, I_{ef}. This value of I_{ef} may be determined from the values of I_{ef} at nominated cross-sections as follows:

(a) For a simply-supported span, the value at midspan.

(b) In a continuous beam;

  (i) for an interior span, half the midspan value plus one quarter of each support value; or

  (ii) for an end span, half the midspan value plus half the value at the continuous support.

(c) For a cantilever, the value at the support.

For the purpose of the above determinations, the value of I_{ef} at each of the cross-sections nominated in (a) to (c) above is given by—

$$I_{ef} = I_{cr} + (I - I_{cr})(M_{cr}/M_s)^3 \leq I$$

where

M_{cr} = the cracking moment at the section (see Clause 8.1.4.1); and

M_s = the maximum bending moment at the section, based on the short-term serviceability load or the construction load.

Alternatively, as a further simplification but only for reinforced members, I_{ef} at each nominated cross-section may be taken as equal to—

(i) for rectangular sections . . . . $0.045bd^3$; or

(ii) for T and L-sections . . . . $0.045b_{ef}d^3\,(0.7 + 0.3b_w/b_{ef})^3$.

8.5.3.2 *Long-term deflection* For reinforced or prestressed beams, that part of the deflection which occurs after the short-term deflection shall be calculated as the sum of—

(a) the shrinkage component of the long-term deflection, determined from the estimated shrinkage properties of the concrete and the principles of mechanics; and

(b) the additional long-term creep deflections, determined by multiplying the short-term concrete deformations due to loads and prestress by appropriate creep coefficients.

8.5.3.3 *Multiplier method for long-term deflection of reinforced beams* In the absence of more accurate calculations, the additional long-term deflection of a reinforced beam due to creep and shrinkage may be calculated by multiplying the immediate deflection caused by the sustained load considered, by a multiplier, k_{cs}, given by—

$$k_{cs} = [2 - 1.2(A_{sc}/A_{st})] \geq 0.8$$

where A_{sc}/A_{st} is taken at—

(a) midspan, for a simply-supported or continuous beam; or

(b) the support, for a cantilever beam.

8.5.4 Deemed to comply span-to-depth ratios for reinforced beams For reinforced beams of uniform cross-section subject to uniformly distributed loads only and where the live load, q, does not exceed the dead load, g, beam deflections shall be deemed to comply with the requirements of Clause 2.4.2 if the ratio of effective span to effective depth is not greater than the value given by—

$$L_{ef}/d = \left[\frac{k_1(\Delta/L_{ef})b_{ef}E_c}{k_2 F_{d.ef}}\right]^{1/3}$$

where

Δ/L_{ef} = the deflection limit selected in accordance with Clause 2.4.2

$F_{d.ef}$ = the effective design load per unit length, taken as—

(a) $(1.0 + k_{cs})g + (\psi_s + k_{cs}\psi_l)q$ for total deflection; or

(b) $k_{cs}g + (\psi_s + k_{cs}\psi_l)q$ for the deflection which occurs after the addition or attachment of the partitions.

where

k_{cs} is determined in accordance with Clause 8.5.3.3 and ψ_s and ψ_l are given in AS 1170.1.

k_1 = I_{ef}/bd^3, which may be taken as

= 0.045 for rectangular sections, or

= $0.045(0.7 + 0.3b_w/b_{ef})^3$ for T- and L-sections

k_2 = the deflection constant, taken as—

(a) for simply-supported beams, 5/384; or

(b) for continuous beams, where in adjacent spans the ratio of the longer span to the shorter span does not exceed 1.2 and where no end span is longer than an interior span—

(i) 1/185 in an end span; or

(ii) 1/384 in interior spans.

8.6 CRACK CONTROL OF BEAMS

8.6.1 Crack control for flexure in reinforced beams Flexural cracking in reinforced beams shall be deemed to be controlled if the following requirements are satisfied:

(a) The centre-to-centre spacing of bars near the tension face of the beam shall not exceed 200 mm.

(b) The distance from the side or soffit of a beam to the centre of the nearest longitudinal bar shall be not greater than 100 mm.

For the purpose of (a) and (b) above, a bar having a diameter less than half the diameter of the largest bar in the cross-section shall be ignored.

8.6.2 Crack control for flexure in prestressed beams Flexural cracking, in a prestressed beam, shall be deemed to be controlled if, under the short-term service loads, the resulting maximum tensile stress in the concrete does not exceed $0.25\sqrt{f'_c}$ or, if this stress is exceeded, by providing reinforcement or bonded tendons, or both, near the tensile face and limiting either—

(a) the calculated maximum flexural tensile stress under short term service loads to $0.6\sqrt{f'_c}$; or

(b) both—

(i) the increment in steel stress near the tension face to 200 MPa, as the load increases from its value when the extreme concrete tensile fibre is at zero stress to the short-term service load value; and

(ii) the centre-to-centre spacing of reinforcement, including bonded tendons, to 200 mm.

8.6.3 Crack control in the side face of beams For crack control in side faces of beams where the overall depth exceeds 750 mm, longitudinal reinforcement, consisting of Y12 bars at 200 mm centres, or Y16 bars at 300 mm centres, shall be placed in each side face.

8.6.4 Crack control at openings and discontinuities Reinforcement shall be provided for crack control at openings and discontinuities in a beam.

8.7 VIBRATION OF BEAMS Vibration of beams shall be considered and appropriate action taken where necessary to ensure that the vibrations induced by machinery, or vehicular or pedestrian traffic, will not adversely affect the serviceability of the structure.

8.8 T-BEAMS AND L-BEAMS

8.8.1 General Where a slab is assumed to provide the flange of a T-beam or L-beam, the longitudinal shear capacity of the flange-web connection shall be checked in accordance with Clause 8.4.

For isolated T-beams or L-beams, the shear strength of the slab flange on vertical sections parallel to the beam shall also be checked in accordance with Clause 8.2.

8.8.2 Effective width of flange for strength and serviceability In the absence of a more accurate determination, the effective width of the flange of a T-beam or L-beam for strength and serviceability shall be taken as—

(a) T-beams . . . . $b_{ef} = b_w + 0.2a$; and

(b) L-beams . . . . $b_{ef} = b_w + 0.1a$; and

where a is the distance between points of zero bending moment, which for continuous beams, may be taken as $0.7L$.

In both (a) and (b) above, the overhanging part of the flange considered effective shall not exceed half the clear distance to the next member. The effective width so determined may be taken as constant over the entire span.

8.9 SLENDERNESS LIMITS FOR BEAMS

8.9.1 General Unless a stability analysis is carried out, beams shall comply with the limit specified in Clauses 8.9.2 to 8.9.4, as appropriate.

8.9.2 Simply-supported and continuous beams For a simply-supported or continuous beam, the distance L_l between points at which lateral restraint is provided shall be such that L_l/b_{ef} does not exceed the lesser of $180b_{ef}/D$ and 60.

8.9.3 Cantilever beams For a cantilever beam having lateral restraint only at the support, the ratio of the clear projection L_n to the width, b_{ef}, at the support shall be such that L_n/b_{ef} does not exceed the lesser of $100b_{ef}/D$ and 25.

8.9.4 Reinforcement for slender prestressed beams For a prestressed beam in which L_l/b_{ef} exceeds 30, or for a prestressed cantilever beam in which L_n/b_{ef} exceeds 12, the following reinforcement shall be provided—

(a) stirrups providing a steel area, A_{sv}, in accordance with Clause 8.2.8; and

(b) additional longitudinal reinforcement, consisting of at least one bar in each corner of the compression face, such that—

$$A_{sc} \geq 0.35A_{pt}f_p/f_{sy}$$

SECTION 9 DESIGN OF SLABS FOR STRENGTH AND SERVICEABILITY

9.1 STRENGTH OF SLABS IN BENDING

9.1.1 General The strength of a slab in bending shall be determined in accordance with Clauses 8.1.1 to 8.1.6 except that for two-way reinforced slabs, the minimum strength requirements of Clause 8.1.4.1 shall be deemed to be satisfied by providing minimum tensile reinforcement such that A_{st}/bd is not less than one of the following:

(a) Slabs supported by columns . . . . $1.0/f_{sy}$.

(b) Slabs supported by beams or walls . . . . $0.8/f_{sy}$.

(c) Slab footings . . . . $0.8/f_{sy}$.

9.1.2 Reinforcement and tendon distribution in two-way flat slabs In two-way flat slabs, at least 25 percent of the total of the design negative moment in a column-strip and adjacent half middle-strips shall be resisted by reinforcement or tendons or both, located in a cross-section of slab centred on the column and of a width equal to twice the overall depth of the slab or drop panel plus the width of the column.

9.1.3 Detailing of tensile reinforcement in slabs

9.1.3.1 *General procedure for arrangement* Tensile reinforcement shall be arranged in accordance with the following as appropriate:

(a) Where the bending moment envelope has been calculated, the termination and anchorage of flexural reinforcement shall be based on a hypothetical bending-moment diagram formed by displacing the calculated positive and negative bending-moment envelopes a distance D along the slab from each side of the relevant sections of maximum moment. Nevertheless, the following shall apply:

   (i) Not less than one-third of the total negative moment reinforcement required at a support shall be extended a distance $12d_b$ or D, whichever is greater, beyond the point of contraflexure.

   (ii) At a simply-supported discontinuous end of a slab, not less than one-half of the total positive moment reinforcement required at midspan shall be anchored by extension past the face of the support for a distance of $12d_b$ or D, whichever is greater, or by an equivalent anchorage.

   Where no shear reinforcement is required in accordance with Clause 8.2.5 or Clause 9.2, the extension of the mid-span positive moment reinforcement past the face of the support may be reduced to $8d_b$ if at least one-half of the reinforcement is so extended, or to $4d_b$ if all the reinforcement is so extended.

   (iii) At a support where the slab is continuous or flexurally restrained, not less than one-quarter of the total positive moment reinforcement required at midspan shall continue past the near face of the support.

   (iv) Where frames incorporating slabs are intended to resist lateral loading, the effects of such loading on the arrangement of the slab reinforcement shall be taken into account but in no case shall the lengths of reinforcement be made less than those shown in Figures 9.1.3.2 and 9.1.3.4, as appropriate.

(b) Where the bending moment envelope has not been calculated, the requirements of Clauses 9.1.3.2. to 9.1.3.4, as appropriate to the type of slab, shall be satisfied.

9.1.3.2 *Deemed-to-comply arrangement for one-way slabs* For one-way slabs continuous over two or more spans where—

(a) the ratio of the longer to the shorter of any two adjacent spans does not exceed 1.2; and

(b) the live loads may be assumed to be uniformly distributed and the live load, q, is not greater than twice the dead load, g,

the arrangement of tensile reinforcement shown in Figure 9.1.3.2 shall be deemed to comply with Clause 9.1.3.1(a).

Where adjacent spans are unequal, the extension of negative moment reinforcement beyond each face of the common support shall be based on the longer span.

For one-way slabs of single span the arrangement of tensile reinforcement shown in Figure 9.1.3.2, for the appropriate end support conditions, shall be deemed to comply with Clause 9.1.3.1(a).

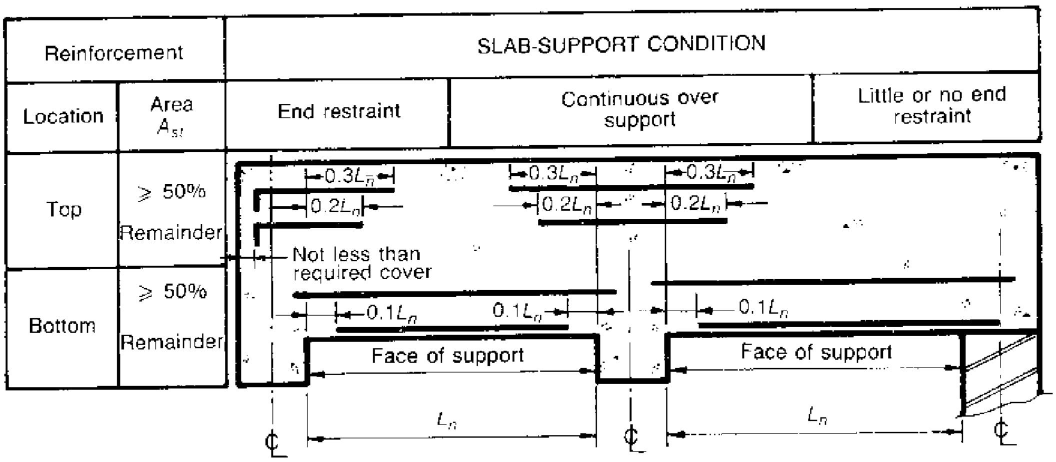

FIGURE 9.1.3.2 ARRANGEMENT OF REINFORCEMENT

9.1.3.3 *Deemed-to-comply arrangement for two-way slabs supported on beams or walls* For two-way simply-supported or continuous rectangular slabs supported by walls or beams on four sides, the arrangement of tensile reinforcement, shown in Figure 9.1.3.2 and further prescribed herein, shall be deemed to comply with Clause 9.1.3.1(a).

The arrangement shall apply to each direction.

Where a simply-supported or continuous slab is not square, the arrangement shall be based on the span, L_n, taken as the shorter span.

Where adjacent continuous rectangular slabs have unequal shorter spans, the extension of negative moment reinforcement beyond each face of a common support shall be based on the span, L_n, taken as the longer of the shorter spans.

Negative moment reinforcement provided at a discontinuous edge shall extend from the face of the support into the span for a distance of 0.15 times the shorter span.

At an exterior corner of a two-way rectangular slab supported on four sides and restrained against uplift, reinforcement shall be provided in both the top and the bottom of the slab. This reinforcement shall consist of two layers perpendicular to the edges of the slab and extend from each edge for a distance not less than 0.2 times the shorter span. The area of the reinforcement in each of the four layers shall be not less than—

(a) for corners where neither edge is continuous . . . . 0.75 A_{st}; and

(b) for corners where one edge is continuous . . . . 0.5 A_{st};

where A_{st} is the area of the maximum positive moment reinforcement required at mid-span.

Any reinforcement provided may be considered as part of this reinforcement.

9.1.3.4 *Deemed-to-comply arrangement for two-way flat slabs* For multispan, reinforced, two-way flat slabs, the arrangement of tensile reinforcement, shown in Figure 9.1.3.4 and further prescribed herein, shall be deemed to comply with Clause 9.1.3.1(a).

Where adjacent spans are unequal the extension of negative moment reinforcement beyond each face of the common support shall be based on the longer span.

All slab reinforcement perpendicular to a discontinuous edge shall be extended (straight, bent or otherwise) past the internal face of the spandrel, wall or column for a length —

(a) *for positive moment reinforcement* not less than 150 mm except that it shall extend to the edge of the slab if there is no spandrel beam or wall; and

(b) *for negative moment reinforcement* such that the calculated force is developed at the internal face in accordance with Clause 13.1.

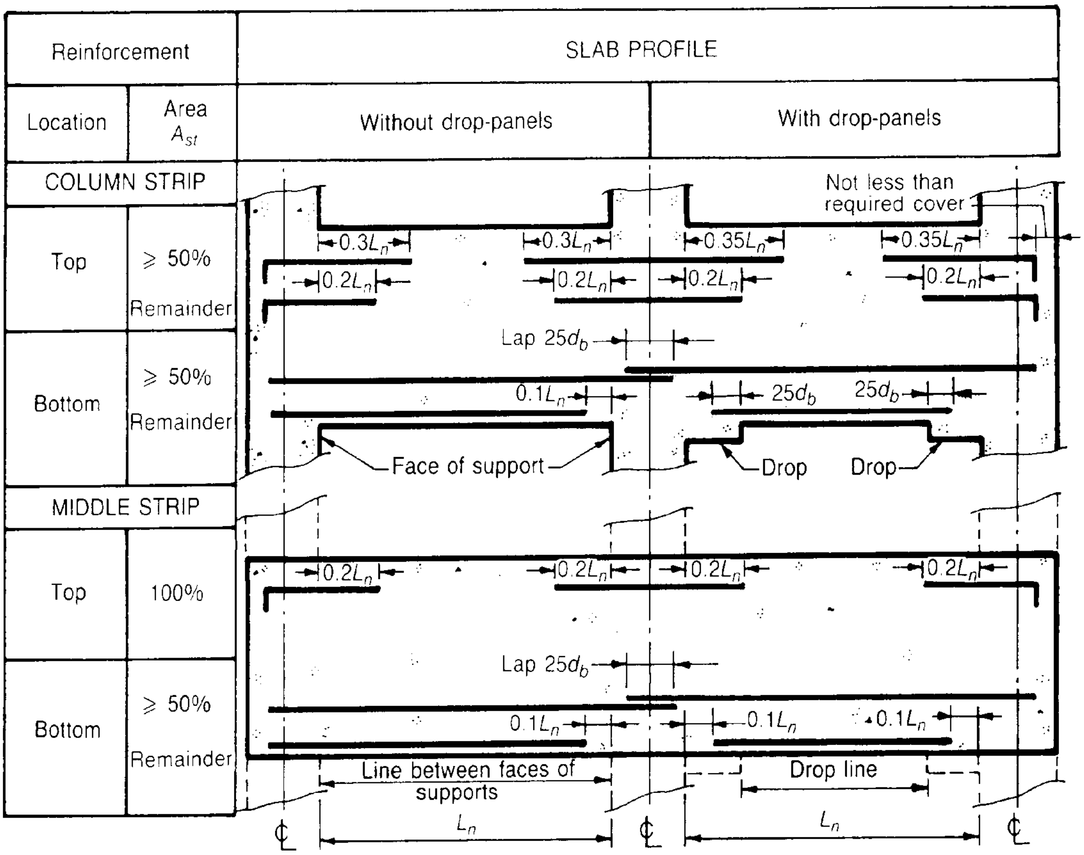

FIGURE 9.1.3.4 ARRANGEMENT OF REINFORCEMENT

9.1.4 Spacing of reinforcement and tendons The minimum clear distance between parallel bars (including bundled bars), ducts and tendons shall be such that the concrete can be properly placed and compacted in accordance with Clause 19.1.3. The maximum spacing of reinforcement and tendons shall be determined in accordance with Clause 9.4.

9.2 STRENGTH OF SLABS IN SHEAR

9.2.1 General For the purpose of this Clause, the following definitions and symbols apply to flat slabs:

Critical shear perimeter—the perimeter defined by a line geometrically similar to the boundary of the effective area of a support or concentrated load and located at a distance of $d_{om}/2$ therefrom (see Figure 9.2.1(A)).

Critical opening—any opening through the thickness of a slab where an edge, or part of the edge, of the opening is located at a clear distance of less than $2.5b_o$ from the critical shear perimeter (see Figure 9.2.1(A)).

Effective area of a support or concentrated load—the area totally enclosing the actual support or load and for which the perimeter is a minimum (see Figure 9.2.1(A)).

Shear head—an arrangement of reinforcement or fabricated steel sections at a support, designed and constructed so that shear failure will not occur within the shear head.

NOTE: The design of shear heads is not covered in this Standard.

Torsion strip—a strip of slab of width a, whose longitudinal axis is perpendicular to the direction of M^*_v (see Figure 9.2.1(B)).

a = the dimension of the critical shear perimeter measured parallel to the direction of M^*_v (see Figure 9.2.1(B))

b_o = the dimension of an opening (see Figure 9.2.1(A))

b_w = the width of the web of a spandrel beam (see Figure 9.2.1(B))

D_b = the overall depth of a spandrel beam (see Figure 9.2.6)

D_s = the overall depth of a slab or drop panel as appropriate

d_{om} = the mean value of d_o, averaged around the critical shear perimeter

M^*_v = the bending moment transferred from the slab to a support in the direction being considered (see Figure 9.2.1(B))

u = the effective length of the critical shear perimeter (see Figure 9.2.1(A))

y_1 = the larger overall dimension of a closed tie (see Figure 9.2.6)

β_h = the ratio of the longest overall dimension of the effective loaded area, Y, to the overall dimension, X, measured perpendicular to Y (see Figure 9.2.1(A)).

9.2.2 Application The strength of a slab in shear shall be determined in accordance with the following:

(a) Where shear failure can occur across the width of the slab, the design shear strength of the slab shall be calculated in accordance with Clause 8.2.

(b) Where shear failure can occur locally around a support or concentrated load, the design shear strength of the slab shall be taken as ϕV_u where V_u is calculated in accordance with one of the following as appropriate:

(i) Where M^*_v is zero, V_u is taken as equal to V_{uo} calculated in accordance with Clause 9.2.3.

(ii) Where M^*_v is not zero, V_u is calculated in accordance with Clause 9.2.4.

9.2.3 Ultimate shear strength where M^*_v is zero The ultimate shear strength of a slab where M^*_v is zero, V_{uo}, is given by either—

(a) where there is no shear head—

$$V_{uo} = ud_{om}(f_{cv} + 0.3\sigma_{cp})$$